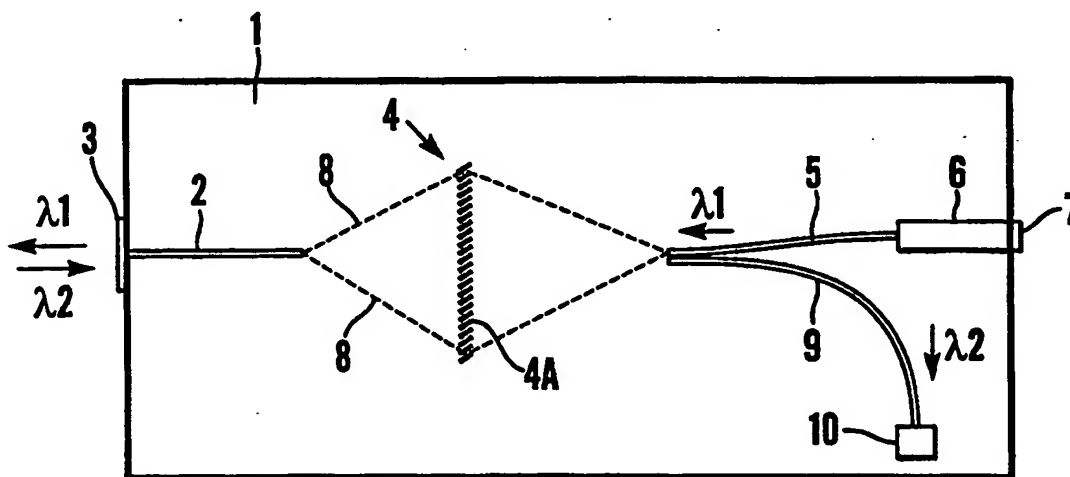


## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/GB98/03831 <b>(22) International Filing Date:</b> 18 December 1998 (18.12.98)  <b>(30) Priority Data:</b> 9727013.6                      23 December 1997 (23.12.97)      GB  <b>(71) Applicant:</b> BOOKHAM TECHNOLOGY LTD. [GB/GB]; 90 Milton Park, Abingdon, Oxon OX14 4RY (GB).  <b>(72) Inventor:</b> ASGHARI, Mehdi; 53 Godolphin Close, Freshbrook, Swindon SN5 8RN (GB).  <b>(74) Agent:</b> UNWIN, Stephen, Geoffrey; Fry, Heath & Spence, The Old College, 53 High Street, Horley, Surrey RH6 7BN (GB).		<b>(81) Designated States:</b> AU, CA, CN, IL, JP, KR, SG, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i>

(54) Title: AN INTEGRATED OPTICAL TRANSCEIVER



## (57) Abstract

An integrated optical transceiver comprising: a laser cavity formed between first and second feedback elements (3, 7), wavelength selective means, e.g. a diffraction grating (4), within the laser cavity for determining a lasing wavelength thereof and a light receiver (10), one of the feedback elements (3) being partially transmissive at the lasing wavelength to enable the transceiver to emit radiation at the lasing wavelength, and the wavelength selective means (4) being arranged to receive light through the feedback element (3) and transmit light of a selected wavelength, differing from the lasing wavelength, to the light receiving means (10).

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## AN INTEGRATED OPTICAL TRANSCEIVER

### TECHNICAL FIELD

This invention relates to an integrated optical transceiver and more particularly a transceiver employing an inter cavity demultiplexer resonator for use in optical communication systems.

### BACKGROUND ART

Multi-wavelength optical communication networks can significantly increase transmission capacity, enhance system flexibility and allow for more flexible and novel system management schemes. A major problem with the cost-effective realisation of such systems is the achievement of stable multi-wavelength transceiver and detector devices with accurate channel wavelength definition and low temperature sensitivity. The latter is to conserve wavelength registration and so allow communication of different devices at different parts of the system that may be at different temperatures. Wavelength selected Distributed Feed Back (DFB) devices used in the prior art suffer from requiring accurate temperature control, lack of wavelength definition on fabrication and high coupling losses on coupling the channels into a single output.

Integration of active or passive wavelength selective devices within laser or detector structures to form integrated multi-wavelength transmitter or receiver devices capable of transmitting or detecting a number of wavelengths simultaneously has been proposed. It is also known that such wavelength selective devices can be formed inside a laser cavity to allow laser oscillation on a number of wavelength channels. The wavelength selective device used in such arrangements is usually a grating based structure typically integrated with lenses or mirrors to perform the required beam manipulation.

The present invention aims to improve upon such devices by providing an integrated multi-wavelength transceiver.

### DISCLOSURE OF INVENTION

According to a first aspect of the present invention there is provided an integrated optical transceiver comprising a laser cavity formed between first and second feedback elements, wavelength selective means within the laser cavity for determining a lasing wavelength of the laser cavity and light receiving means, at least one of the feedback elements being partially transmissive at the lasing wavelength so as to permit the transceiver to emit radiation of the lasing wavelength, and the wavelength selective means being arranged to receive light through one of the feedback elements and transmit light of a selected wavelength, differing from the lasing wavelength, to the light receiving means.

Such a transceiver is capable of detecting incoming data on one or a set of wavelengths and simultaneously transmitting data on a different wavelength or set of wavelengths.

The wavelength selective means determines the lasing wavelength by being part of the laser cavity and the selected wavelength transmitted to the light receiving means and so determines both the wavelength transmitted by the transceiver and the wavelength received by the transceiver.

According to another aspect of the invention there is provided a matched pair of such transceivers.

Other features of the invention will be apparent from the following description and from the subsidiary claims of the specification.

### BRIEF DESCRIPTION OF DRAWINGS

The invention will now be further described, merely by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram showing a first embodiment of an integrated optical transceiver according to the invention; and

Figure 2 is a schematic diagram showing a second embodiment of an integrated optical transceiver according to the invention.

### BEST MODE OF CARRYING OUT INVENTION

A single wavelength transmission and detection transceiver is described below but the arrangement described can be extended to any number of wavelength channels.

Figure 1 shows an optical chip 1, such as a silicon-on-insulator chip, on which the transceiver is formed. An integrated waveguide 2, such as a silicon rib waveguide, extends from a first feedback element 3, such as a polished, partly anti-reflective (AR) coating formed on a facet at one end of the waveguide 2 towards wavelength selective means 4, such as a transmission grating formed by a series of narrow, shallow grooves 4A, etched in the surface of the silicon chip. A further waveguide 5 is formed on the chip 1 at a position to receive light at a selected angle from the transmission grating 4 and leads, via an optical amplifier 6, such as a semiconductor laser amplifier chip, to a second feedback element 7, such as a high reflection (HR) coated facet of the laser amplifier 6. In the example shown, the grating comprises a linear array of chirped period apertures so it also focusses the light transmitted therethrough.

Light travelling along the waveguide 2 towards the transmission grating 4 diverges into the silicon layer, as represented by the dashed lines 8 as it leaves the waveguide 2. Light leaves the transmission grating 4 in the form of an interference pattern generated by the linear array of chirped period apertures forming the grating in the well-known manner and comprises a series of peaks at different angular positions relative to the axis of the grating (i.e. an axis perpendicular to the grating and co-linear with the waveguide 2), each peak comprising light of a particular wavelength or wavelength band.

The waveguide 5 is positioned so as to receive light of a selected wavelength  $\lambda_1$ , which is to be the wavelength transmitted by the transceiver. Light of this wavelength is amplified in a laser cavity formed between the AR coating 3 and the HR coating 7 in a known manner and as the AR coating is only partially reflective, part of this light is transmitted from the transceiver through the AR coating 3 as the output of the transceiver at the wavelength  $\lambda_1$ .

Another waveguide 9 is also provided on the chip at a selected angle so as to receive light of a second wavelength  $\lambda_2$  from the transmission grating 4 and transmits this light to a detector 10 such as a photodiode.

The spacing required between the waveguides 5 and 9 so they receive the respective wavelengths  $\lambda_1$  and  $\lambda_2$  would typically be in the order of 10 - 20 microns depending upon the dimensions and geometry of the arrangement.

The transmission grating thus acts to direct light of the second wavelength  $\lambda_2$  received by the transceiver through the partly anti-reflective coating 3 to the photodiode 10.

The wavelength selective structure 4 is thus integrated as part of a laser cavity formed between the partly anti-reflection (AR) coated facet 3 and the high reflection (HR) coated facet 7 of the semi-conductor laser amplifier chip 6. The grating 4 is used to set the relative wavelengths of both the transmitted and received data inside the same chip. The grating 4 sets the transmitted wavelength of the laser by being part of the laser cavity and acting as a wavelength selective filter. At the same time, the grating 4 also acts as a bandpass filter ensuring that the detector 10 is illuminated by the correct range of wavelengths.

The wavelength selectivity of the grating 4, therefore, enables the formation of a closed cavity for laser oscillation at one wavelength  $\lambda_1$  and the free detection of another wavelength  $\lambda_2$  at the detector. The detector 10 is physically part of

the laser resonator but is separated from it in the wavelength domain. The photodiode 10 terminating the waveguide 9 acts as a highly efficient absorber and prevents the formation of oscillations on that wavelength.

Figure 1 schematically illustrates one embodiment of such a transceiver. Data on wavelength  $\lambda_2$  is coupled into the device and is demultiplexed by the grating structure 4 to illuminate the detector 10. As indicated above, the example shown in figure 1 incorporates a chirped focusing grating 4 to perform both demultiplexing and focusing.

Figure 2 shows another embodiment which used a combination of collimating and focusing mirrors 11 etched in the silicon chip together with a reflection grating 12. The mirrors 11 and reflection grating 12 can be formed by deep etches in the surface of the silicon chip.

The lasing wavelength of the laser is determined by the grating demultiplexer 12 by providing wavelength selective feedback at  $\lambda_1$  in the optical amplifier 6.

The detected wavelength  $\lambda_2$  received by the device is directed by the mirrors 11 and grating 4 to the detector 10. The grating 4 is thus again included in the laser cavity, multiplexing and demultiplexing the radiated lasing wavelength from that of the input data during each round trip cycle. This isolates the detector 9 and forms a laser cavity between the high reflection coated facet 7 of the laser, through the grating demultiplexer 12 to the partially anti-reflection coated facet 3 of the chip.

If the wavelengths  $\lambda_1$  and  $\lambda_2$  are significantly different, the anti-reflection coating 3 can be designed to have a lower value (i.e. be less reflective) for the detected wavelength  $\lambda_2$  to improve coupling efficiency and a higher value (i.e. be more highly reflective) for the transmitted wavelength  $\lambda_1$  to reduce the laser threshold.

The transceivers described above have a number of significant advantages:

The inclusion of the passive grating demultiplexer removes any wavelength registration problems between the transmitted and detected wavelengths of transceivers located at different parts of the system. This is due to the fact that the detected and transmitted wavelengths are set by the same passive demultiplexer device. For instance, in the above example, the emitted laser light at  $\lambda_1$  is determined by the demultiplexer geometry which can be defined very accurately and fabricated to high tolerances, e.g. by photolithographic processes which enable the grating to be formed to sub-micron accuracy. This wavelength is thus automatically matched to the detected wavelength of another transceiver as this will also use exactly the same demultiplexer but with the laser and detector wavelengths swapped. Since the passive demultiplexer is effectively identical in both cases the wavelengths will be identical and thus automatically self-aligned.

The inclusion of the grating element forces laser oscillation on a particular wavelength defined by the grating. This wavelength can be set very accurately (to better than 0.05 nm) and may, on the one hand, be designed to be sufficiently narrow to allow reduction of chirp and dispersion penalty but, on the other hand, sufficiently broad to enable stable and linear light current response (by averaging out mode hopping effects).

Also, by tapering-in the waveguide 5 coupling the laser to the grating i.e. by reducing the height and/or the width of the waveguide 5 as it approaches the grating 4 or 12, the spectral line-width of the light coupled into the laser can be reduced.

The transceiver also has reduced temperature sensitivity. Temperature dependence arises from two factors:

- i) Thermal expansion changing the grating pitch. The thermal expansion coefficient of silicon is  $4.6 \times 10^{-6} \text{ K}^{-1}$  and for typical device designs this



results in a change of emitted laser wavelength of 0.7nm over the temperature range -40 to 85°C.

- ii) Refractive index variation with temperature: this changes the operating wavelength of the grating. The change in refractive index with temperature for Si is  $1.86 \times 10^{-4} \text{ K}^{-1}$ . For typical device designs, over the temperature range -40 to 85°C, this will result in a wavelength change of approximately 9nm.

The resulting wavelength variations with refractive index are thus an order of magnitude larger than the corresponding variations due to thermal expansion. However, even a 9nm shift over the stated 125°C temperature range due to index variation is significantly less than that which would have been obtained using prior art such as a Fabry-Perot laser.

It should also be noted that wavelength variation with temperature due to an active (laser) element on device performance is avoided as the wavelength is set by the passive grating device.

The resulting reduction in wavelength shift with temperature combined with the reduction in emitted laser line-width reduces the required tolerance on channel wavelengths significantly. With a transceiver device working with the two wavelengths of 1310nm and 1550nm, for example, a channel width of approximately 100nm is required if prior art Fabry-Perot lasers are employed without any temperature stabilisation. This can be reduced to 10nm if the transceiver described herein is employed with such lasers.

Tapering of the detector waveguide 9, i.e. by reducing the height and/or increasing the width so as to increase the width of the waveguide mode as it approaches the grating 4, 12, can also be used to accommodate the wavelength variation of the incoming data over this 9nm range with less than 1dB penalty on channel loss. For example, the waveguide 9 can be tapered

out from its standard 4 microns width to 20 microns resulting in a broadening of the detector response so that any changes in emitted laser wavelength due to temperature can be accommodated.

For large channel separations, such as the 1310nm to 1550nm as mentioned above, it is difficult to achieve the required channel separation inside the free spectral range (FSR) of the grating. To overcome this the grating is designed for operation outside the FSR but in such a way that crosstalk with any of the other modes present is avoided or minimised. To ensure this, the device is designed so that the wavelengths corresponding to potentially interfering modes are not present at the input to the waveguide 9.

The transceiver described above can also be designed to transmit and/or receive on more than one wavelength band by providing further waveguides on the chip to receive other wavelengths into further laser cavities similar to that described above and to receive other wavelengths into further detectors similar to that described above. With waveguides approximately 4 microns wide, spaced about 10 microns apart, it would, for example, be possible to form up to 32 waveguides in the focal plane of the grating so enabling the transceiver to transmit on 16 wavelengths and receive on 16 wavelengths.

The transceiver arrangement described above also facilitates two possible methods for monitoring the light emitted from the laser. The first is to sample the light inside the laser cavity using the grating. The grating can be designed to carry a small but finite proportion of the laser power in a lower or higher order diffraction mode. This can be coupled to a further tap-off waveguide 13 and coupled to a further photodiode 14 (see Fig. 2). By correct design, the spatial separation of this higher order mode should be sufficiently different from that of the emitted and detected wavelengths  $\lambda_1$  and  $\lambda_2$  to allow well-spaced waveguides at the focal plane.

The second method is based on monitoring the power emitted from the back facet 7 of the laser amplifier 6. This can be reflected from an angled mirror and coupled to a suitable detector. In this case, the laser amplifier 6 would be mounted away from the edge of the chip to allow room for the mirror and detector to be formed on the chip.

It will be appreciated that in order to maximise the receiver sensitivity of the transceiver, the detected wavelength  $\lambda_2$  should preferably coincide with a peak of the diffraction profile produced by the grating 4, 12.

It will also be appreciated that in the design of the AR coating 3 a compromise has to be reached between the desire to reduce laser cavity losses (to reduce laser threshold current) by increasing its reflectivity for wavelength  $\lambda_1$  and the desire to increase the receiver sensitivity by reducing its reflectivity for wavelength  $\lambda_2$  (to reduce coupling losses for incoming data).

An AR coating having a reflectivity of about 20% (to both wavelengths), for example, will result in a 1 dB increase in coupling loss for the received power, (i.e. a 1dB reduction in sensitivity) compared to a coating with a 0% reflectivity. The corresponding increase in laser threshold current will be around 30% compared to the use of an HR coating with 80% reflectivity.

As indicated above, the transceiver described herein is preferably formed on a silicon-on-insulator (SOI) chip. An SOI chip enables easy integration of the various components of the transceiver and relatively low fabrication costs. Further details of SOI chips and rib waveguides formed thereon are given in WO95/08787.

Methods of mounting components such as photodiode detectors on an SOI chip are described in GB2307786A and in co-pending application no. GB9702559.7 (publication no. GB2315595A). A tapered rib waveguide

structure is described in co-pending application no. 9702579.5 (publication no. GB2317023A).

The fabrication of transmission and reflection grating in the surface of an optical chip by electron beam or photolithographic techniques is well known so will not be described in detail. The transmission grating 4 would typically be formed of shallow grooves a fraction of a micron in depth (e.g. 0.2 microns) and width and a few microns in length. The period is chirped and would typically vary from a fraction of a micron to a few microns.

The reflection grating 12 would typically be formed of deep etched features with reflecting surfaces 5 - 20 microns wide, spaced about 5 - 20 microns apart and the grating may typically have a length of about 500 microns.

The mirrors 11 would also be formed by deep etches, extending all the way through the light guiding layer, and be from a few hundred microns to a few millimetres wide. The mirrors are preferably concave as shown in Fig. 3 so as to collimate and focus the light and may also have a reflective coating such as - a coating of aluminium applied thereto. As indicated above, the grating and mirrors can be fabricated with great accuracy using known photolithographic etching processes, e.g. to within an accuracy of about 0.2 microns. Such accuracy is repeatable so enabling transceivers to be fabricated with accurately matched transmission and receiving wavelengths.

CLAIMS

1. An integrated optical transceiver comprising a laser cavity formed between first and second feedback elements, wavelength selective means within the laser cavity for determining a lasing wavelength of the laser cavity and light receiving means, at least one of the feedback elements being partially transmissive at the lasing wavelength so as to permit the transceiver to emit radiation of the lasing wavelength, and the wavelength selective means being arranged to receive light through one of the feedback elements and transmit light of a selected wavelength, differing from the lasing wavelength, to the light receiving means.
2. A transceiver as claimed in Claim 1 in which the wavelength selective means comprises a diffraction grating.
3. A transceiver as claimed in Claim 2 comprising a first optical waveguide, arranged to transmit and receive light to and from the grating at a first angle corresponding to the angle said lasing wavelength is received from the grating and a second optical waveguide arranged to receive light from the grating at a second angle corresponding to the angle said selected wavelength is received from the grating.
4. A transceiver as claimed in Claim 3 in which the second waveguide has a relatively wide receiving end for receiving light at a range of angles from the diffraction grating and a narrower transmission portion for transmitting the light to the light receiving means.
5. A transceiver as claimed in Claim 2, 3 or 4 formed on an optical chip in which the diffraction grating comprises a transmission grating or reflection grating formed by a series of recesses in the surface of the chip.

6. A transceiver as claimed in any preceding claim in which the wavelength selective means is arranged to determine both the lasing wavelength and the selected wavelength with an accuracy of 10nm or less, irrespective of temperature changes.
7. A transceiver as claimed in any preceding claim in which the said one of the feedback elements comprises an anti-reflective coating.
8. A transceiver as claimed in Claim 7 in which the anti-reflective coating is more transmissive to the said selected wavelength than the lasing wavelength.
9. A transceiver as claimed in any preceding claim in which the other of the feedback elements comprises a highly reflective coating, preferably arranged to reflect at least 80% of light of the lasing wavelength.
10. A transceiver as claimed in any preceding claim in which the wavelength selective means and the lasing cavity are arranged such that the transceiver is able to transmit light at a plurality of lasing wavelengths.
11. A transceiver as claimed in any preceding claim in which the wavelength selective means and the light receiving means are arranged such that the transceiver is able to detect light at a plurality of selected wavelengths.
12. A transceiver as claimed in Claim 3 and Claim 10 or 11 in which a plurality of optical waveguides are provided each being arranged to receive a respective lasing wavelength or selected wavelength from the wavelength selective means.
13. A transceiver as claimed in Claim 12 in which the receiving ends of the said plurality of optical waveguides are spaced 20 microns or less from each other and preferably 10 microns or less from each other.

14. A transceiver as claimed in any preceding claim arranged such that the or each lasing wavelength and the or each selected wavelength are selected so as not to interfere with each other.
15. A transceiver as claimed in any preceding claim comprising output monitoring means arranged to monitor light transmitted through the other of the feedback elements to monitor the power of the emitted radiation.
16. A transceiver as claimed in Claim 3 in which the diffraction grating is arranged to diffract light at the said lasing wavelength in a higher or lower order diffraction mode than that received by the said first optical waveguide and comprising output monitoring means for receiving said lasing wavelength in the higher or lower order diffraction mode to monitor the power output of the emitted radiation.
17. A transceiver as claimed in any preceding claim in which the light receiving means comprises a light detecting diode.
18. A transceiver as claimed in any preceding claim integrated on a silicon-on-insulator chip.
19. A transceiver as claimed in any preceding claim having a channel width of 10nm or less.
20. An integrated optical transceiver substantially as hereinbefore described with reference to the accompanying drawings.
21. A pair of transceivers as claimed in any preceding claim in which the lasing wavelength of one transceiver corresponds to the selected wavelength of the other.

22. A pair of transceivers as claimed in Claim 22 in which the wavelength selective means of the respective transceivers each comprise a diffraction grating formed to a similar degree of accuracy whereby the respective lasing wavelength and selected wavelength of each transceiver are determined by essentially identical means and so are automatically matched with each other.



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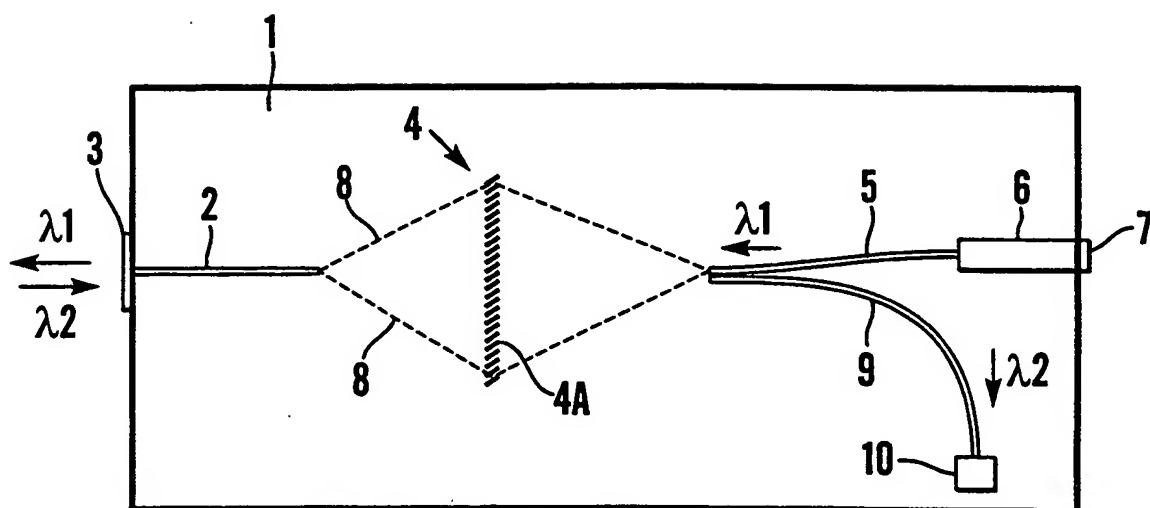


Fig. 1

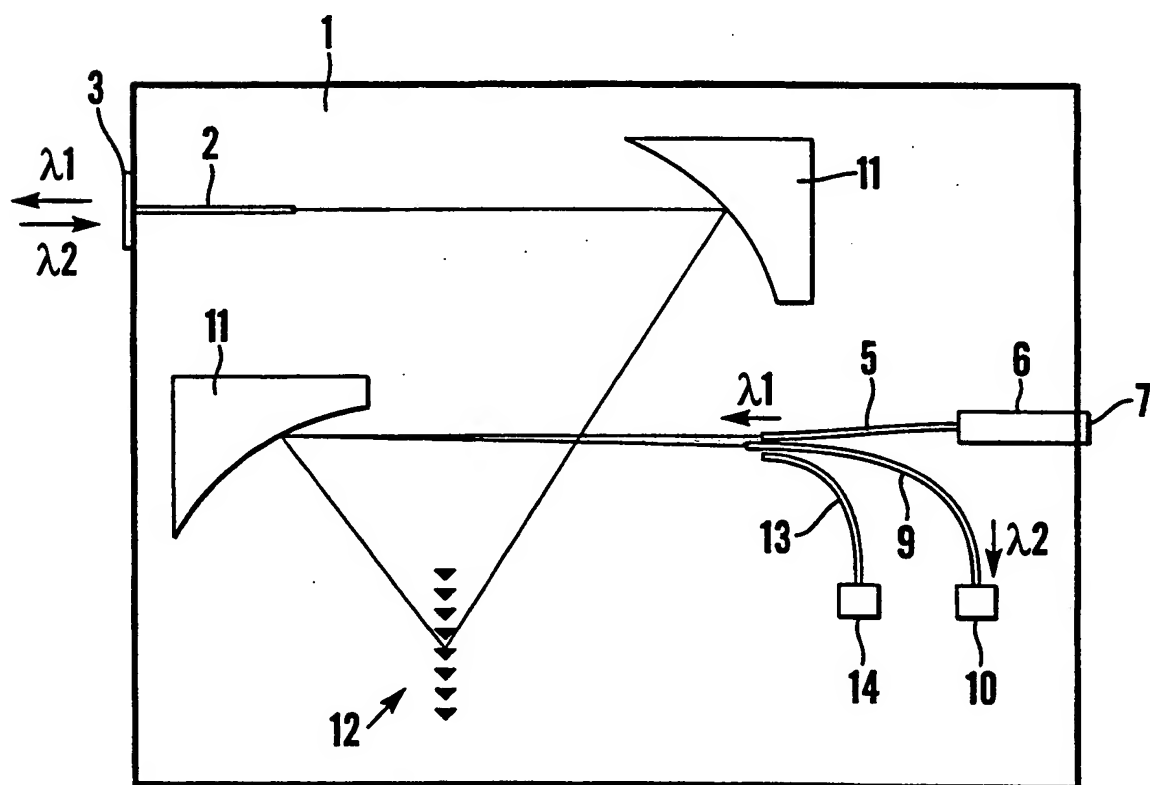


Fig. 2

# INTERNATIONAL SEARCH REPORT

Int. Patent Application No.

PCT/GB 98/03831

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 H01S3/025 G02B6/12 G02B6/42

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04B H01S G02B H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 195 19 486 A (BOSCH GMBH ROBERT) 28 November 1996 see abstract see column 1, line 67 - column 2, line 21 see figure 1	1-3, 5, 17, 20
A	US 4 786 133 A (GIDON PIERRE ET AL) 22 November 1988 see abstract see column 1, line 7 - line 54 see figure 1	1-3, 11-13, 20
A	EP 0 585 094 A (SHARP KK) 2 March 1994  see abstract see column 2, line 1 - line 24 see figure 1	1, 2, 17, 20
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "Z" document member of the same patent family

Date of the actual completion of the international search

26 March 1999

Date of mailing of the international search report

07/04/1999

Name and mailing address of the ISA

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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 98/03831

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>EP 0 575 750 A (GEN INSTRUMENT CORP)  29 December 1993  see column 6, line 9 - line 40  see figure 4</p> <p style="text-align: center;">-----</p>	<p>1,2,6,7,  9,10</p>

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Information on patent family members

International Application No

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